THE EFFECT OF PARK-N-RIDES

ON GREENHOUSE GAS EMISSIONS

by

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ABSTRACT

Over the past decade, rising greenhouse gas emissions (GHG emissions) have put public transit in the forefront of sustainable transportation. To improve transit accessibility and attract riders, Park-n-Ride (PnR) facilities have been built on the periphery of cities. By providing convenient parking facilities, agencies encourage drivers to shift modes in their single occupancy vehicle (SOV) and complete their journey by transit.

While PnRs are intended to facilitate more transit riders, the facilities may also carry paradoxical consequences. Do PnRs actually reduce the distance traveled by SOVs? Does a multi-modal trip offset emissions from a theoretical SOV drive-only trip? Critics have challenged the environmental efficiency of PnRs, claiming the magnitude of the modal shift may not necessarily be reflected in GHG emissions. Drivers may still make long trips by car to reach the PnR.

This study evaluates the magnitude of GHG emissions saved from transit ridership, based on SOV PnR users in the Denver metro area. By comparing the multi-modal trip against a theoretical SOV drive-only trip, the effects from GHG emissions are weighed. Theoretically, the further a person drives to reach a PnR, the less of an impact transit has on reducing GHG emissions.

Results showed that PnRs located at inner-corridor stations are less effective at reducing GHG emissions than end of line stations. PnRs near downtown provide an

incentive for longer SOV drives. Consequently, drivers who make long transit access trips can outweigh the benefits of transit usage due to increased vehicle emissions.

The form and content of this abstract are approved. I recommend its publication.

Approved: Wesley E. Marshall

DEDICATION

To my mother and father, John and Nancy Truong, who have always supported me endlessly in my education- from kindergarten through graduate school.

To my boyfriend, Ricky Nguyen, who has supported me through my research and long nights of studying, and is never shy of joining me on a multi-modal adventure.

Finally, to all of my mentors, bosses, and friends in the transportation industry- thank you for inspiring a life-long passion.

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CHAPTER I

INTRODUCTION

Concerns about environmental sustainability have led to an increased consciousness in seeking more sustainable transportation. A good portion of the carbon footprint derives from transport activities, making it more important than ever to reduce single occupancy vehicles (SOVs), utilize alternative modes of transportation, and reduce vehicular emissions. In cities with congested urban corridors and limited parking capacity, park-n-ride (PnR) facilities have become a popular measure toward increasing transit ridership. PnR facilities allow for commuters to park their vehicles and transfer onto larger feeder systems going into the metro area. Serving as a magnet to draw more drivers out of their cars and into public transit, PnRs can improve the accessibility of transit.

While there are several studies that discuss the effects of public transit on environmental sustainability, there is little literature that explores the link between PnR and greenhouse gas emissions (GHG emissions). In theory, vehicle emissions should decrease as drivers shift their mode to public transit. Although the environmental effects from a lone driver may seem marginal, the sum of a larger group utilizing PnR facilities multiplies these effects. A modal shift from SOV to mass public transit can add up quickly, and since many PnRs are located within suburbs and on the periphery of cities, they often provide a common access point that facilitates transit to riders along the most congested portions of their trip. Thus, the effects from transit usage may add up to a reduction in the overall carbon footprint as compared to fully SOV-driven trips. As a result, public transit has been touted as one of the most effective means in reducing GHG

emissions from SOVs because shifting modes from private vehicles to public transit creates displaced car trip that correspond with displaced vehicle miles traveled (VMT).

While PnRs are designed to facilitate maximum transit usage, they may also carry paradoxical environmental consequences. The magnitude of the modal shift may not necessarily be reflected in significant GHG emissions reductions as drivers could be driving a long portion of the trip by car. In other words, a driver's individual choices may not necessarily in the best interests of the environment. Placed against driving, a rational individual might only use a PnR if its generalized cost is lower than the one for the drive-only trip (J. Holguin-Veras et al., 2012). For example, avoiding parking costs may be a driver's primary reason for taking transit; therefore, free parking becomes the motivator. In the context of individualized costs, a driver is more likely to use a free PnR when the drive-only trip carries parking fees. In fact, drivers may go out of their way to access a PnR facility if doing so results in a significant savings in parking costs. These challenges, amongst others, make the environmental effects from PnRs multi-faceted and in need of further study.

This thesis will seek to better understand the relationship between PnRs and GHG emissions through a case study of Denver, Colorado. Using data from the Regional Transportation District (RTD) of Denver and the Denver Regional Council of Governments (DRCOG), the study will analyze trip patterns for SOV PnR light rail users across metro Denver. Trip distances will be determined for the multi-modal trip, including a SOV transit access portion and a light rail portion, as well as the calculated hypothetical SOV drive-only trip distance. Using these distances, the study estimates the GHG emissions saved by riders using PnRs and light rail transit with respect to their

relative effect on the overall commute. Because carbon dioxide (CO_2) is the main element in transport-based GHG emissions, CO_2 equivalents will be used to measure the environmental effects of each mode. Theoretically, riders create the most environmental benefits when the transit access trip is shorter than the light rail trip, reducing vehicular emissions from an SOV drive-only trip while still providing convenient access to the PnR facility. In a broader scope, this study will add to the larger library of literature examining how public transportation usage can affect the environment.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

PnR facilities have become highly popular in the United States and Europe. These car ports intercept motorists heading into the city and provide transfers onto bus, rail, or carpool for the remainder of their journey. PnR facilities integrate the private auto into the public transport system, allowing for drivers to evade the low speeds of inner city driving, the inevitable congestion delays, and the high costs of parking in the city. PnRs can improve accessibility to transit while creating more parking availability outside the urban corridor. Most metropolitan areas suffer from heavy traffic congestion and have limited parking capacity; building new parking facilities and structures can be limited by physical constraints. PnRs allow for parking capacity to increase without locating the structures in congested city centers. The PnR system is well suited for suburban commuters because the auto portion of the trip provides connectivity to the PnR site, while the transit portion enables riders to reach their final destination at a minimal social cost (Holguin, 2012). Riders are afforded an opportunity to avoid the most congested portion of the commute and can save money in parking costs. Additionally, transit agencies can focus operations on segments of the network with the most sufficient demand, as opposed to providing multiple local feeders.

Transportation policy makers tend to favor PnRs, as they are generally saleable to the public (Karamycheve, 2011) and can help increase transit ridership fairly quickly. The facilities expand choices for transport options and provide an opportunity for alternative modes without forcing people completely out of their cars. However, the broader issue at hand is not whether people shift modes; the problem lies in whether there is a reduction in the amount of energy used and greenhouse gases emitted.

In a recent Brookings Institution report (Brown, Southworth et al., 2008), transit-rich regions were found to have a lower carbon footprint. Land use in these regions tended to be more mixed-use and compact developments, qualities found in transit oriented developments (TODs). Residents of TODs tend to own fewer vehicles, drive less, walk more, and have better access to transit. On a national scale, the American Public Transportation Association (APTA) quantified emissions displaced by transit through avoided car trips at 16 million metric tons (MMT) of CO_2-equivalent per year, offset by 12 MMT CO_2-emissions produced by transit (Bailey 2007; Davis and Hale 2007); thus, there was a net savings of 4 MMT CO_2 emissions. Logically, if PnRs are being used efficiently and effectively, there would be a reduction in vehicular emissions. As evidenced in academic literature, the large passenger capacity of public transit can allow for a sizable reduction in GHG emissions produced by SOVs.

Although PnRs are a popular gateway to increasing transit ridership, there are limited publications that explore the sustainability effects from these facilities. Do PnR facilities reduce the miles driven by SOVs? The impacts on the environment are rather uncertain. Several arguments challenge the environmental efficiency of these facilities. First, the magnitude of the modal shift may not necessarily reflect on GHG emissions; a potentially long part of the trip can still be made by car (Gantele, 2008). Transit access trips are generally longer than the trip leg between the PnR location and the urban center (Parkhurst, 2000, Meet et al., 2008b). PnRs may induce unexpected and counterproductive effects, such as commuters who reach the train station by car instead of walking or biking. Additionally by facilitating accessibility, PnR facilities may potentially attract new driving trips, thus having a negative effect on vehicle emissions.

Finally, the long term effects of PnRs may help proliferate urban sprawl by creating more vehicle accessibility outside the city center (Gantele, 2008). Paradoxically, each of these potential impacts raises challenges for PnRs in fulfilling their sustainable purpose.

A study from the Swiss Federal Office of Energy (Guillaume-Gentil et al., 2004) reported mixed results for Swiss PnRs in regard to environmental efficiency. Notably, PnRs located near city centers turn out to be counterproductive, while PnRs along regional transport networks showed better energy efficiency. Overall, the results of the Swiss study were inconclusive. The methods used for the study in Switzerland encompass several aspects that affect environmental sustainability, including the cost efficiency, the effects on roadway congestion, and the availability of long-term parking in metro areas. While the study covers multiple issues, it is difficult to determine any true findings as many of the factors were inconclusive. For this study, the primary focus will be to highlight GHG emissions in terms of CO_2-equivalents.

More recently, a research study from the Netherlands found that PnRs may create unintended effects, which not only limit transit usage, but may even increase vehicle travel in the metro area. The primary consequence was *"abstraction from public transport,"* where individuals shifted to driving from transit that had been previously been making the entire trip via public transit before the PnR was introduced (Mingardo, 2013). Other unintended consequences include additional trip generation, abstraction from bike, and park and walk issues. Abstraction from bike describes individuals who once made all or some of their commute by bike and now drove to the station. Park and walk depicts people who parked at the station but then walked somewhere nearby and did not use transit at all (Jaffe, 2013). Such users potentially displace transit riders who use

the PnR for transit access. Each of these unintended consequences raised concerns about negative environmental impact from PnRs. Surveys from the Netherlands also asked how users would make the same trip in the absence of the PnR. Of these 39.2% claimed they would not make the trip whatsoever. The methodology behind this study interviewed 738 PnR users in Rotterdam; whereas the Denver survey analyzed in this study looks at over 2,000 responses. From the Rotterdam pool, only 47.3% of users took the PnR for work-related activities. While the Dutch study provides interesting insights for European PnRs at rail-based stations, there is a lack of literature studying the environmental effects from American-based PnRs.

As car ownership and vehicle emissions continue to rise, alternative transportation is struggling to keep pace in counterbalancing the environmental impacts. As a result, it is important to know whether or not PnR facilities can help mitigate GHG emissions. PnRs seem promising, as they tend to capture drivers outside the most congested roads and provide a valuable travel link for their trips. Although commuters still make a portion of their trip by private vehicle, the net effects of a large group's modal shift could lead to promising effects on the planet's carbon footprint. However, the literature shows that there is reason to doubt these benefits. Within this study, the effect of PnRs on GHG emissions will be studied more closely, seeking to find if the net benefits from transit usage can outweigh private vehicle usage.

CHAPTER III

STUDY OVERVIEW

As of 2012, RTD operates 74 PnR facilities in the Denver metro region. Of these, nineteen PnRs provide light rail transit (LRT) services. Table 1 provides a listing of parking spaces provided at each station, from least to greatest, as well as the station typology. Parking for a station serving residential neighborhood has different demands than a station in a TOD/mixed-use area.

Table 1: PnR parking availability and station typology

Light Rail Station	# of Parking Spaces	Station Type
30th & Downing	27	Residential
Orchard	48	Commercial
Belleview	59	Commercial
Evans	99	Residential
Yale	129	Residential
Dry Creek	235	TOD/Mixed-use
Dayton	250	Residential
Alameda	302	Commercial
County Line	338	Commercial
Littleton-Downtown	361	TOD/Mixed-use
Colorado	363	Commercial
University	540	School
Southmoor	788	TOD/Mixed-use
Arapahoe at Village Center	817	TOD/Mixed-use
Englewood	910	TOD/Mixed-use
Nine Mile	1225	Commercial
Littleton-Mineral	1227	TOD/Mixed-use
I-25 & Broadway	1248	TOD/Mixed-use
Lincoln	1734	TOD/Mixed-use

Parking fees for PnR usage are based upon whether a vehicle is registered within the RTD district. In-district residents may park at the PnR facility for free during the first 24-hours; after this period, a fee of $2 per day is assessed. Out-of-district residents are

charged a fee of $4 per day. Exemptions for out-of-district vehicle fees applies to active duty U.S. military assigned in Colorado, college students enrolled in at least 10 credit hours attending class at least three days a week, drivers of vehicles with a valid disable placard or license plate, and residents who recently moved into the district and have filled an exemption application.

Data

In 2008, RTD conducted an on-board survey of its riders in the Denver metro area. The survey, administered by NuStats, was conducted on local, limited, express, regional, SkyRide, and all light rail routes. Data were collected during the months of February, March, and April 2008, resulting in a total of 23,865 usable surveys. Riders were surveyed for the immediate one-way trip. Surveyors were asked to provide information about their transit access trip, mode of access, origin and destination, and transit route. Additionally, surveyors were asked various socio-economic questions, fare payment method, and what alternative mode would have been taken if transit was not available. According to NuStats, samples from all major bus and light rail routes are at the 95% confidence level.

Before selecting the 2008 RTD on-board survey as the data set for this study, many other options for transit ridership patterns were considered. The RTD Annual License Plate survey provides an annual study of PnR users by origin. The license plate survey is primarily targeted toward seeing how far drivers commute to the PnR, as well as tracking out-of-district users. Any out-of-district commuters are charged daily fees to use the PnR; the cameras used for this survey provide frequent enforcement of this

policy. Unfortunately, the license plate survey lacked destination data for the specific riders. An attempt was made to connect RTD boardings/alighting information to fill the destination void. However, in order to perform this analysis, many layers of assumptions would need to be made. Finally, the more recent DRCOG Regional Travel Survey was obtained in an effort to obtain more accurate origin-destination data for PnR users. Unfortunately, while the data is coded for transit users, the database does not specify bus from light rail. Thus, it would have been difficult to determine the distance traveled by transit, since bus routes and light rail lines vary.

The 2008 RTD on-board survey provided a total of 2,019 surveyors who accessed PnR facilities by SOV and rode light rail for a portion of the commute. Results for transit-access trip distance varied across the region; for end-of-the-line stations (such as Nine Mile and Lincoln), drivers tended to be from more geographically scattered areas. Figure 1 shows a map with the origin and destination of surveyors accessing Nine Mile PnR. Data points from the origin and destination summary were used in analysis of GHG emissions, as described in the Methodology section. Results of the data analysis can be found in the following section.

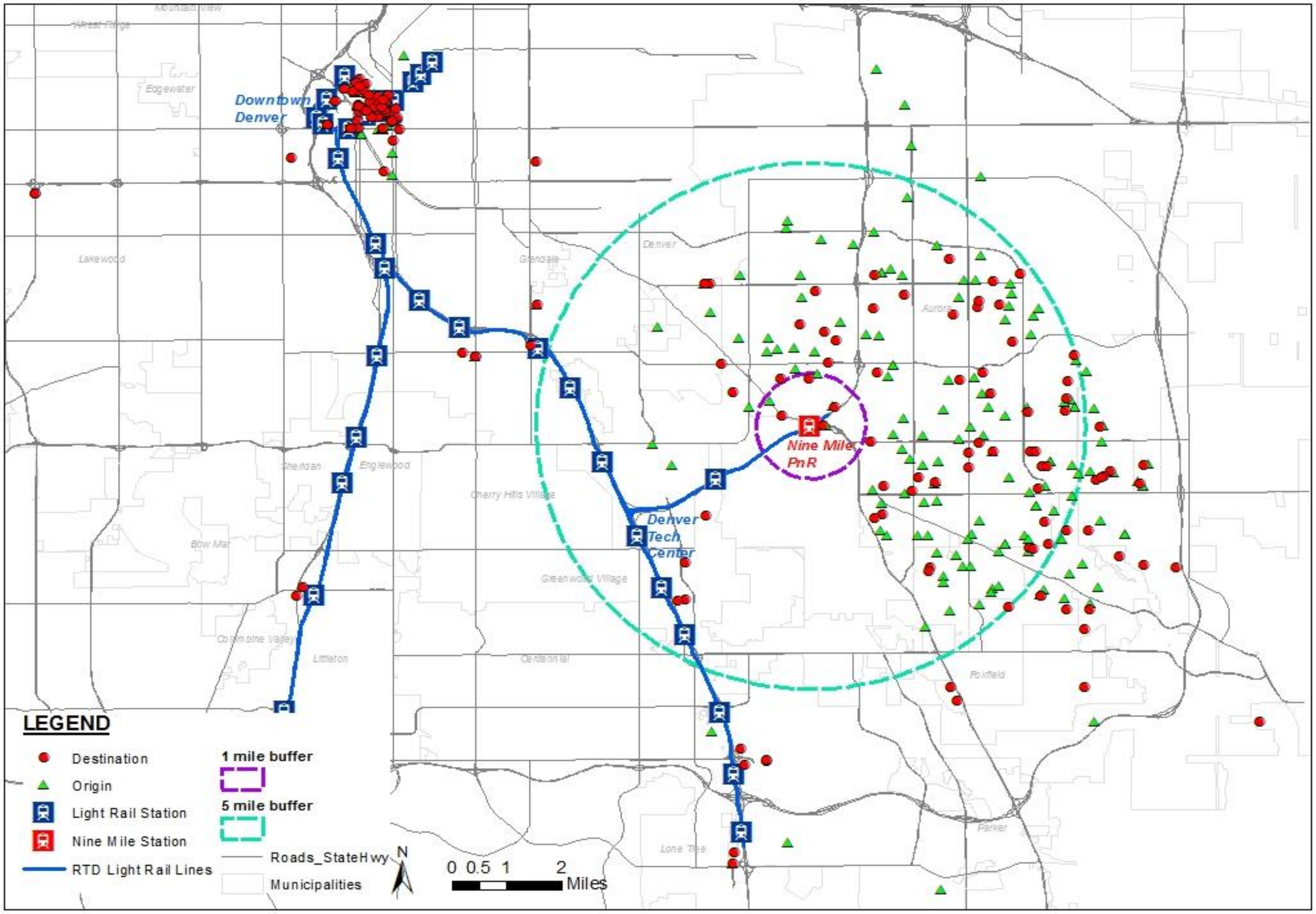

Figure 1: Origins and destination summary for Nine Mile Station PnR

Methodology

Calculating vehicle and transit mileage

This study utilizes data collected from RTD's 2008 on-board survey to gauge ridership patterns and PnR behavior at light rail stations in the Denver metro region. In order to obtain an applicable set of data, several filters were applied to the original set of 23,865 surveys. To compare the effects of PnR providing transit access to drivers, the set was isolated for SOVs accessing the PnR. This provided information to estimate the vehicle miles travel (VMT) displaced by light rail. The filtered data set contains 2,019 surveyed riders who fall within the criteria above.

Using the truncated data, calculations were made to determine the approximate distance riders traveled during their commute. Because the survey asked riders about their immediate one-way trip, some trips were home based while others were work based; nonetheless, all trips contained a transit portion and a vehicle portion. The car-based portion of the trip is referred to as a 'transit access trip'. The transit portion of the trip is referred to as 'transit miles traveled'. The following procedure was used to determine the mileage of each trip:

1. Transit access trip mileage was provided by the surveyors and verified through Google Maps.
2. Transit miles traveled was determined as the distance between the boarding station (PnR location) and the alighting station (destination). This is also referred to as the light rail trip segment.

3. SOV mileage for the hypothetical drive-only trip is estimated by entering the origin and destination addresses in Google Maps. The Google Maps program calculates the best routes based upon shortest distance and shortest drive time.

As shown below, Figure 2 illustrates an example of a rider's transit access trip and light rail trip (steps 1 and 2 in procedure). Figure 3 provides an example using the same rider's data for the theoretical SOV drive-only trip.

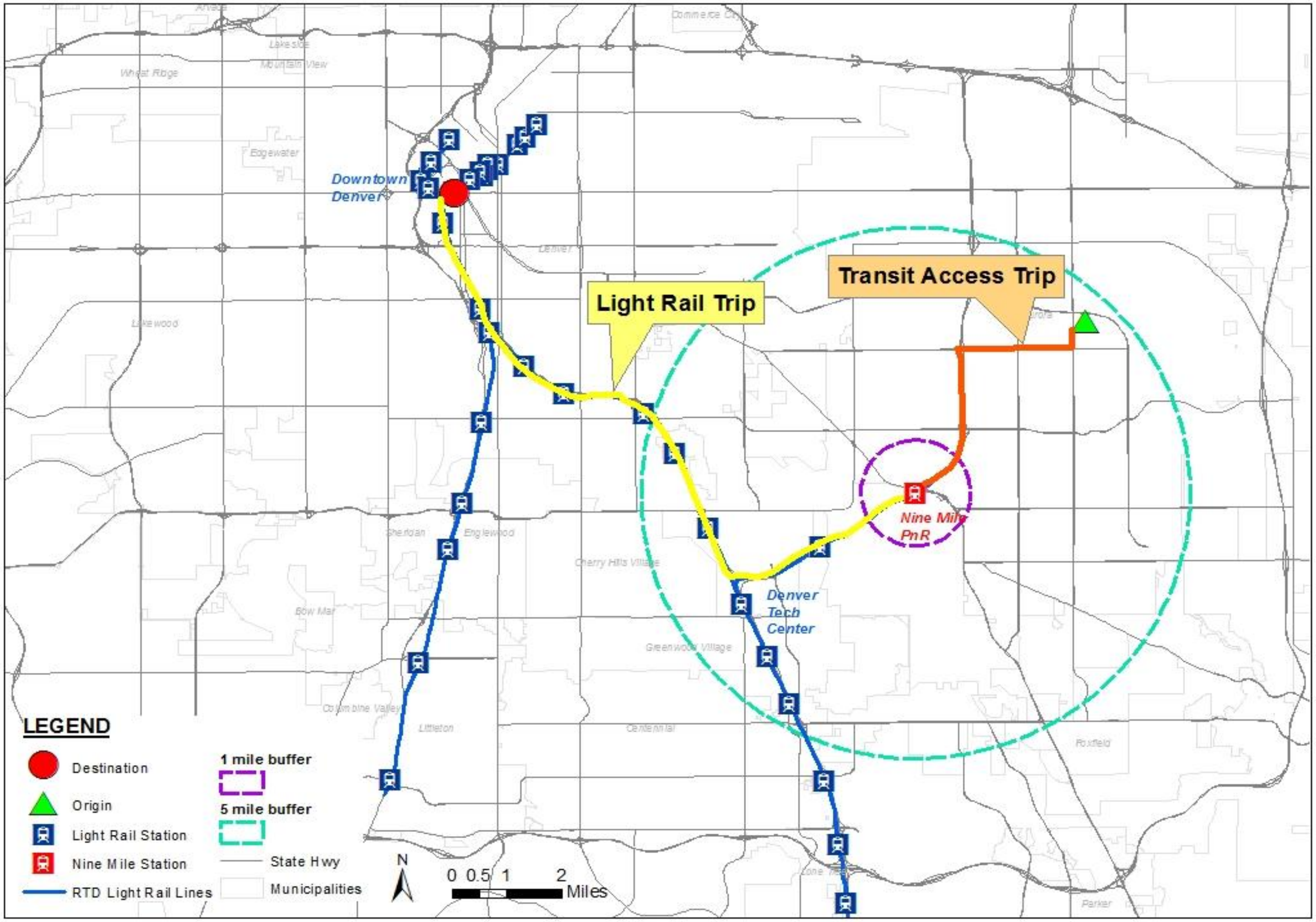

Figure 2: Example of multi-modal trip from PnR

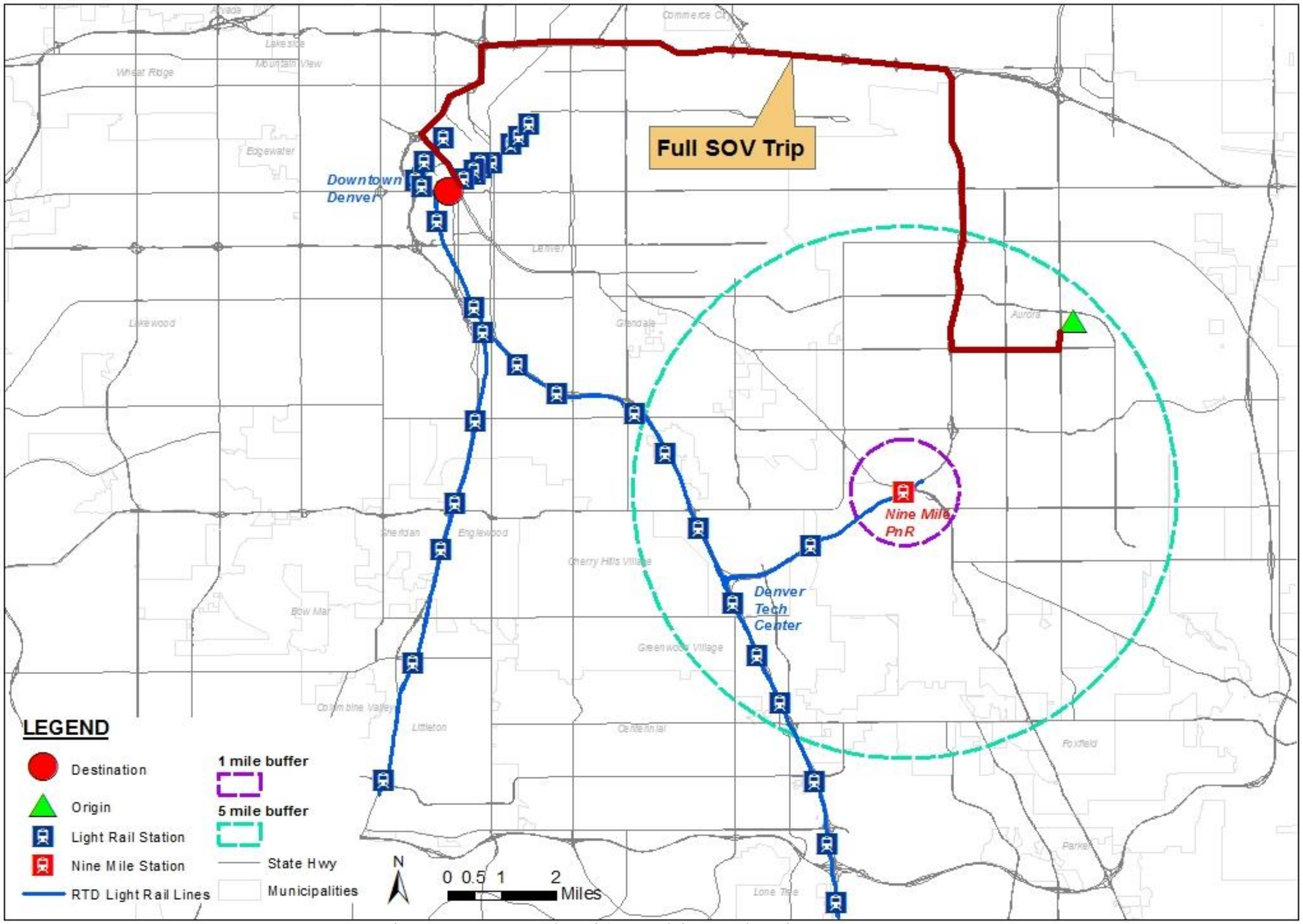

Figure 3: Example of SOV drive-only trip

Calculating GHG emissions

Vehicle emissions from the transit-access trip and theoretical drive-only SOV trip are calculated by using the American Public Transportation Association (APTA)'s methodology for quantifying GHG emissions from transit. The national default value for fleet fuel economy is 20.2 miles per gallon, as reported by the EPA in *Light-Duty Automotive Technology and Fuel Economy Trends: 1973 through 2007*.

$$Fuel\ consumed = VMT \div 20.2\ miles\ per\ gallon \qquad \textit{(Equation 1)}$$

From the fuel consumed of the displaced VMT, carbon dioxide emissions are obtained by using the national default values for GHG emissions, as reported from *The Climate Registry General Reporting Protocol v. 1.0*, Tables 13.1 and 13.4. Carbon dioxide is the primary GHG emitted through human-based transportation activities; thus, carbon dioxide emissions will be the primary GHG emission measured in this study. The default value for carbon dioxide emissions is:

$$CO_2\ \ vehicle\ emissions = \frac{Fuel\ consumed}{8.81\ kg\ CO_2\ per\ gallon\ of\ gasonline} \qquad \textit{(Equation 2)}$$

Environmental impacts from transit are determined from the 2009 RTD Sustainability Survey. GHG impacts for light rail are based upon electricity usage (kilowatts) used for the traction power supply system (TPSS). Additionally, energy usage for other LRT system components, including power for signal houses and stations,

are included in the LRT GHG impacts. Table 2 provides a summary of the LRT system's GHG impact, as well as the carbon dioxide equivalent per passenger mile.

Table 2: Greenhouse Gas Impacts from RTD LRT System, 2009

LRT System Component	Electricity Usage (kWh)	CO_2-Equivalent (kg CO_2)
Traction power system supply	43,766,810	32,695,000
Communication signal house	1,450,420	1,023,000
LRT station power usage	8,817,095	6,221,000
LRT station lighting	44,509	31,000
Total CO_2*-Equivalent from LRT system*		39,970,000
Annual LRT Passenger Miles (2009)		129,248,691
CO_2*-equivalent per Passenger Mile* ($CO_2 Equiv. per\ Passenger\ Mi$)		0.3092

The carbon dioxide equivalent per passenger mile in Denver was calculated to be 0.3092. In comparison, a national found the average of CO_2 emissions per passenger mile on light rail to be 0.202, ranging between 0.113 to 1.689 (M.J. Bradley). Travel Matters, part of the Transportation Research Board, determined the average CO_2 equivalent per transit mile to be 0.35 (TravelMatters). Thus, a value of 0.3092 is in line with national averages for GHG emissions in transit. The carbon dioxide equivalent per passenger mile is used to determine how the actual transit miles traveled impacts the environment, as calculated in equation 3:

$$CO_2\ transit = (CO_2\ Equiv. per\ Passenger\ Mi) \times Transit\ Miles \qquad \textit{(Equation 3)}$$

Carbon dioxide ratio: Multi-modal trip vs. SOV trip

By using the GHG emission calculations for vehicles and transit, a ratio of the carbon dioxide emissions from a multi-modal trip to a SOV trip is determined. This ratio calculates the effect of using light rail relative to a fully SOV drive-only trip by

incorporating the emissions from all modes in the multi-modal and fully SOV trip. A ratio that is less than 1.0 indicates that the multi-modal trip emits fewer GHG emissions. As the ratio value approaches 1.0, the lesser the effect transit has on emissions. If the ratio is greater than 1.0, then the multi-modal trip is producing more emissions than an SOV-drive only trip. In this scenario, it would be more environmentally sustainable to not take public transit.

$$CO_2\ ratio = \frac{(CO_2\ transit\ access) + (CO_2\ light\ rail)}{(CO_2\ SOV\ drive\text{-}only\ trip)} \qquad \textit{(Equation 4)}$$

CHAPTER IV

RESULTS

Using survey data from the 2008 RTD on board survey, travel patterns were analyzed for 2,019 SOV drivers who used PnRs in the Denver metro region. A summary of the transit access statistics is shown in Table 3.

Table 3: Transit access trip statistics

Light Rail Station	# of Parking Spaces	Average Distance (mi)	Minimum Distance (mi)	Maximum Distance (mi)
30th & Downing	27	5.6	0.8	15.4
Orchard	48	3.4	0.9	23.2
Belleview	59	2.8	0.9	15.1
Evans	99	2.9	1.0	11.3
Yale	129	3.4	1.1	13.0
Dry Creek	235	3.6	0.9	15.0
Dayton	250	7.3	0.7	26.2
Alameda	302	5.6	1.0	30.3
County Line	338	7.8	1.0	20.1
Littleton-Downtown	361	4.0	1.0	15.0
Colorado	363	3.5	1.2	20.2
University	540	4.4	1.1	21.3
Southmoor	788	4.2	1.3	15.1
Arapahoe at Village Center	817	5.2	1.2	22.3
Englewood	910	6.0	1.0	25.0
Nine Mile	1225	5.4	1.3	21.4
Littleton-Mineral	1227	5.0	1.1	25.1
I-25 & Broadway	1248	7.3	1.2	30.4
Lincoln	1734	6.7	0.9	30.3

As mentioned in the previous section, Nine Mile station (located at the end of the line) tends to attract a wide range of driver origins, shown in Figure 3. The average distance a commuter drives to reach Nine Mile PnR is 5.4 miles. However, some commuters drive up to 21 miles to reach the station- compared to a light rail trip of only 14 miles. Light rail stations that were more centrally located within the corridor tended to have a lower

average driving distance. At Evans Station, the maximum transit access trip was 11 miles, with an average distance of 2.9 miles.

Trip patterns were determined for both the multi-modal trip, including a SOV transit-access portion and a light rail portion, as well as for the theoretical SOV drive-only trip. A summary of average distances for trips is shown in Table 4.

Table 4: Average distances for Multi-Modal and Hypothetical SOV trip

Light Rail Station	Multi-modal trip		Hypothetical SOV drive-only (mi)
	Transit access trip (mi)	Transit miles traveled (mi)	
30th & Downing	5.6	3.8	9.3
Orchard	3.4	11.7	15.1
Belleview	2.8	12.0	14.8
Evans	2.9	5.7	8.6
Yale	3.4	8.0	11.4
Dry Creek	3.6	15.0	18.6
Dayton	7.3	13.0	20.3
Alameda	5.6	8.1	13.8
County Line	7.8	16.5	24.3
Littleton-Downtown	4.0	10.0	14.0
Colorado	3.5	7.6	11.1
University	4.4	5.6	10.0
Southmoor	4.2	9.4	13.5
Arapahoe at Village Center	5.2	14.0	19.1
Englewood	6.0	7.5	13.5
Nine Mile	5.4	13.9	19.3
Littleton-Mineral	5.0	11.9	16.9
I-25 & Broadway	7.3	5.0	12.3
Lincoln	6.7	16.4	23.1

Based upon the distance of the trips, a carbon dioxide (CO_2) equivalent was calculated for each mode as described in the methodology. Vehicle emissions were determined by using the national average fuel economy and converting into CO_2-equivalents (*Equations 1* and *2*). Light rail impacts are calculated from a factor of CO_2-

equivalent per passenger mile (*Equation 3*). With all of the CO_2-equivalents determined, a ratio of multi-modal trip to SOV trip was calculated. *Equation 4* details the calculations for the CO_2 ratio. Primarily, this ratio was used to determine the relative effect of transit on GHG emissions. Table 5 provides results of the GHG emission analysis, including the average of emissions for each station and the CO_2-equivalent ratio.

Table 5: GHG emission summary and CO_2-equivalent ratio

Light rail station	Transit access emissions (kg CO_2)	Light rail impact (kg CO_2)	SOV drive-only emissions (kg CO_2)	CO_2 Ratio
30th & Downing	2.4230	1.1681	4.0706	0.88
Orchard	1.4762	3.6153	6.5756	0.77
Belleview	1.2176	3.7104	6.4512	0.76
Evans	1.2783	1.7592	3.7598	0.81
Yale	1.4992	2.4736	4.9883	0.80
Dry Creek	1.5860	4.6380	8.1280	0.77
Dayton	3.2009	4.0196	8.8707	0.81
Alameda	2.4601	2.5074	5.9969	0.83
County Line	3.3993	5.0927	10.5828	0.80
Littleton-Downtown	1.7290	3.0920	6.0904	0.79
Colorado	1.5192	2.3551	4.8411	0.80
University	1.9113	1.7233	4.3421	0.84
Southmoor	1.8211	2.8967	5.9070	0.80
Arapahoe at Village Center	2.2565	4.3154	8.3435	0.79
Englewood	2.6297	2.3249	5.9090	0.84
Nine Mile	2.3613	4.3043	8.4327	0.79
Littleton-Mineral	2.1656	3.6920	7.3732	0.79
I-25 & Broadway	3.1763	1.5554	5.3702	0.88
Lincoln	2.9166	5.0657	10.0619	0.79

The closer a CO_2-equivalent ratio is to 1.0, the lesser the benefit transit has on the environment. Conversely, stations with lower ratios would have a greater environmental benefit from transit. In theory, drivers who make longer transit access trips may be negating the positive environmental effects from transit usage, due to the greater SOV

usage over longer distances. From the ratios, it is observed that some stations have a disproportionately higher amount of SOV transit-access miles. Many of the drivers who parked at 30th & Downing station did not originate from nearby neighborhoods. Because this station provides free parking and is located within two miles of the downtown central business district (CBD), it lures drivers who would otherwise make a fully car-based trip into downtown. In this scenario, the PnR serves primarily to save the driver on costs of parking downtown. The graph in Figure 4 provides a graphical analysis of the CO_2 ratios, organized in ascending order of parking spaces provided.

Of the stations with highest ratios, 30th & Downing and I-25 & Broadway station are among the closest PnRs to downtown Denver. Parking fees provide a disincentive for drivers to park downtown, while still maximizing the utility of driving as close as possible to a free parking lot. In this sense, the PnR does not serve a purpose of encouraging sustainable transit ridership. Instead, the PnR facility actually induces driving to the closest free parking possible. These effects are contrary to the overall intent of PnRs. Although these lots are intended to provide better access to public transit, drivers may still make long trips to reach the PnR facility and therefore negate the environmental benefits of using transit.

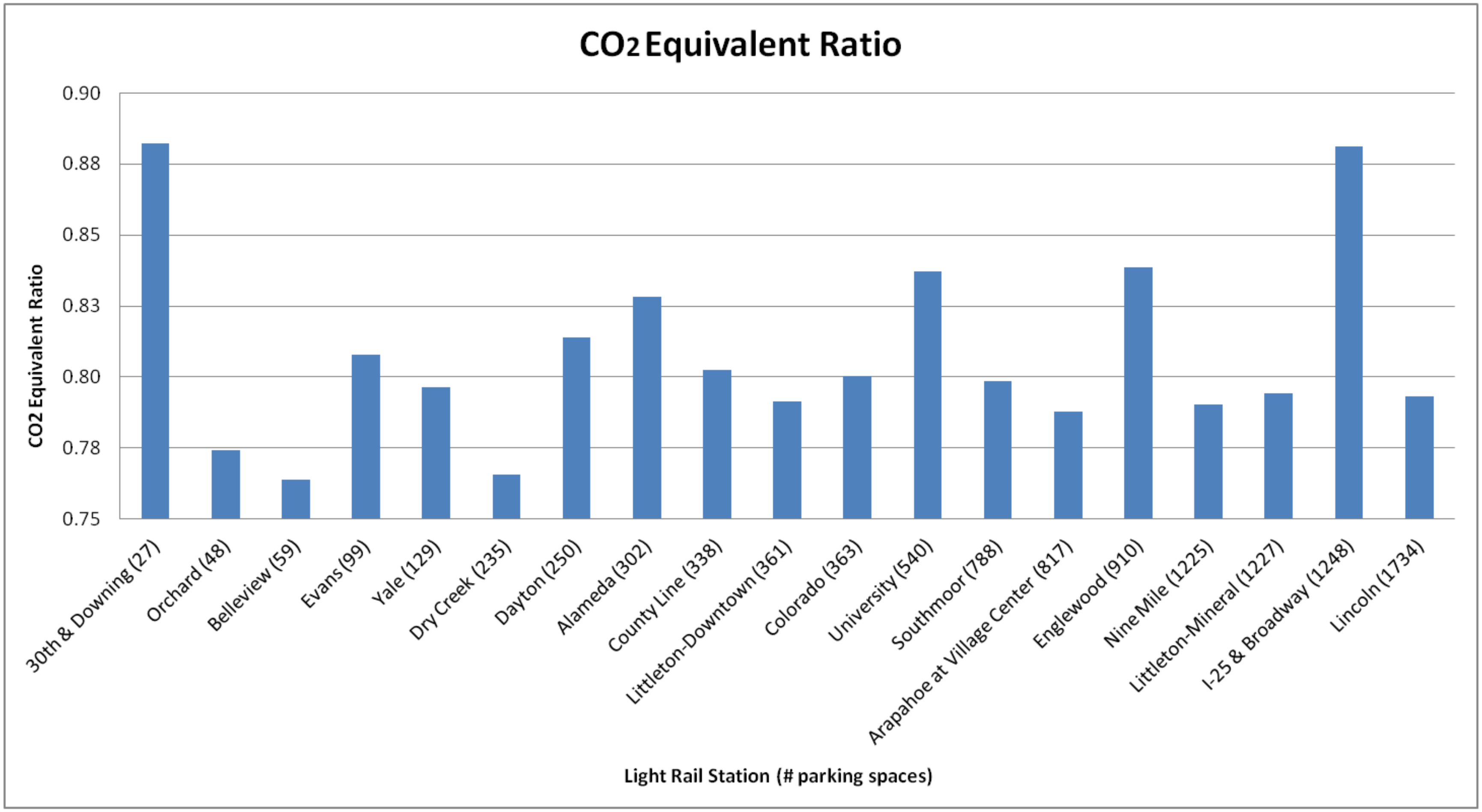

Figure 4: Average CO2-equivalent ratio by station

CHAPTER V

DISCUSSION

Do PnR facilities increase transit ridership? The 2008 RTD on-board survey asked riders how they would have made their trip if transit was not available. Out of the 2019 drivers who used the PnR, over 88% claimed that they would have otherwise driven alone for the full trip, shown in Figure 5. Thus, it would be fair to assume that because a PnR facility was available, this made public transit more accessible to drivers. Most of these individuals fit into the ‘choice rider’ category- individuals who have access to a private vehicle, but have chosen to switch modes in favor of public transit. What makes these riders significant is that alternatively, these same individuals would have been driving the roads in a lone-occupant vehicle. Not only would this increase congestion to roadway networks, but GHG emissions from transportation would also rise.

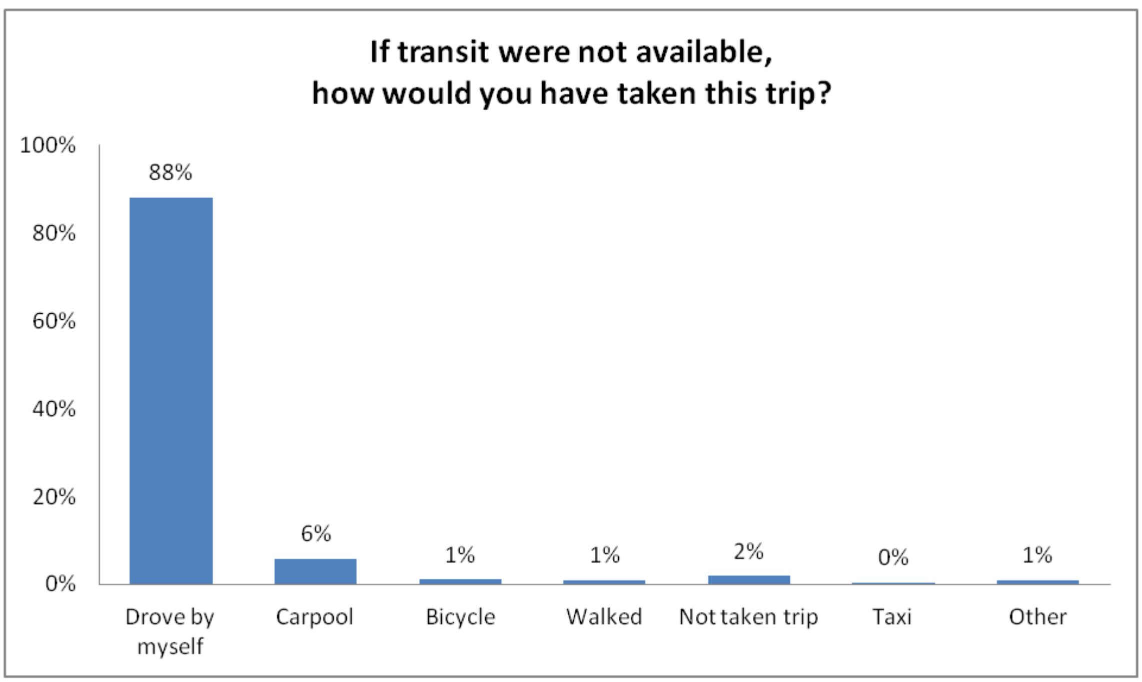

Figure 5: PnR Transit Alternative Question

Parking fees

Parking fees can influence where a driver parks or which mode a rider chooses to take. In the downtown Denver central business district, parking is priced at premium, averaging $16 per day (Denver Business Journal). This incentivizes commuters traveling into the downtown Denver CBD to seek alternative modes and/or free periphery parking. The other large employment center in the Denver metro region is the Denver Tech Center, located south of I-25 and I-225. Although the southeast corridor caters to riders commuting through the DTC, there is a disparity in transit ridership because of free parking. Because parking within the DTC is free of charge, employees have less incentive to leave their vehicles behind and commute by transit. A survey of Denver businesses within one mile of light rail stations found that more than 80% of businesses outside the downtown CBD had free parking right next to their building (DRCOG). The abundance of free parking outside of downtown adds to the disincentive of riding transit.

A notable observation from this study is the parking patterns of Castle Rock drivers. Castle Rock, located 31 miles south of downtown Denver, is not within the RTD district. Because its residents do not pay RTD taxes, riders from Castle Rock must pay to park at all times. Without the first 24 hours free, like other RTD in-district residents enjoy, Castle Rock residents may feel an incentive to find free neighborhood or street-side parking. The closest RTD light rail station with direct street-side parking is at Belleview Station. Belleview is located six miles from Lincoln Station, meaning that drivers are willing to commute an extra 12 miles a day roundtrip in order to save on the $2 per day parking fee.

Parking demand

Prior to construction, parking estimates were determined based upon the DRCOG Regional Travel Demand Model. During the environmental evaluation process, stakeholders had an opportunity to provide input and feedback on the proposed parking lots/structures. Some lots, such as Evans Station, were influenced heavily by community comment and local political will. During the design process, 100 spaces were added to address concerns regarding spillover parking into adjacent residential areas (RTD). The concerns of residents within the Evans Station area were not isolated- many other stations experienced similar push-back from community members during preliminary development (RTD). Remarkably, the only station on the Southeast corridor without a PnR is at Louisiana-Pearl Station. Transit planners had designed this location to provide walk-up service at a neighborhood-based station. It is the only light rail station on the corridor without a parking facility, in spite of its location at the heart of two Denver neighborhoods. Despite the lack of parking provided, ridership at Louisiana/Pearl station is consistently high and has made the station one of the busiest stops outside of central downtown. The distance to the next closest PnR facility from Louisiana-Pearl is I-25/Broadway Station, located 0.8 miles away. The close proximity of these light rail stations to one another lends to the broader topic of station typology and station planning. Planners should be weary of placing a PnR facility at every station along the corridor for the sake of providing parking; in the larger scope of TOD planning and development, mixed-developments may struggle if parking is over-abundant. By limiting PnRs to selective locations where the demand is highest, such as at the end of station lines, corridors can provide more concentrated funnels for drivers to access the corridor from

PnRs. This will not only decrease the need for lower-demand inner-corridor parking lots, but will provide better parking efficiency at the primary lots.

Improving transit access trips with walking/biking

What if all commuters driving less than two miles to a PnR walked or biked to the station? What would be the effects on GHG emissions? After the primary analysis and results for the study were obtained, a secondary analysis of the data was run to determine how many PnR users are driving less than two miles. A standard of two miles was selected based upon national TOD practices for an acceptable biking/walking distance for the average healthy adult. From here, the GHG emissions analysis was re-run with the assumption that each of these drivers would be able to walk or bike to the light rail station. A new CO_2-equivalent ratio for the multi-modal trip versus SOV drive-only trip was found, using similar methodology as before. In this case, the multi-modal trip included a walking/biking portion to access the light rail station and the original light rail trip, shown in *Equation 5*. A summary of these results follows in Table 6 and Figure 6.

$$CO_2\ ratio = \frac{(CO_2\ walking/biking) + (CO_2\ light\ rail)}{(CO_2\ SOV\ drive{-}only\ trip)} \qquad \textit{(Equation 5)}$$

Table 6: Driving trips <2 miles replaced by walking/biking

Light Rail Station	% of Drivers <2 mi	Transit access emissions saved	Walk/Bike CO_2 Ratio	SOV Driver CO_2 Ratio	% Change
30th & Downing	22%	3.49	0.29	0.88	67%
Orchard	46%	5.23	0.55	0.77	29%
Belleview	42%	8.72	0.58	0.76	25%
Evans	41%	10.47	0.47	0.81	42%
Yale	31%	8.72	0.50	0.80	38%
Dry Creek	18%	10.47	0.57	0.77	25%
Dayton	5%	2.62	0.45	0.81	44%
Alameda	19%	10.47	0.42	0.83	50%
County Line	6%	1.74	0.48	0.80	40%
Littleton-Downtown	16%	20.06	0.51	0.79	36%
Colorado	30%	15.70	0.49	0.80	39%
University	38%	22.68	0.40	0.84	53%
Southmoor	30%	29.66	0.49	0.80	39%
Arapahoe at Village Center	22%	13.08	0.52	0.79	34%
Englewood	11%	21.81	0.39	0.84	53%
Nine Mile	6%	11.34	0.51	0.79	35%
Littleton-Mineral	8%	26.17	0.50	0.79	37%
I-25 & Broadway	14%	12.21	0.29	0.88	67%
Lincoln	8%	16.57	0.50	0.79	37%

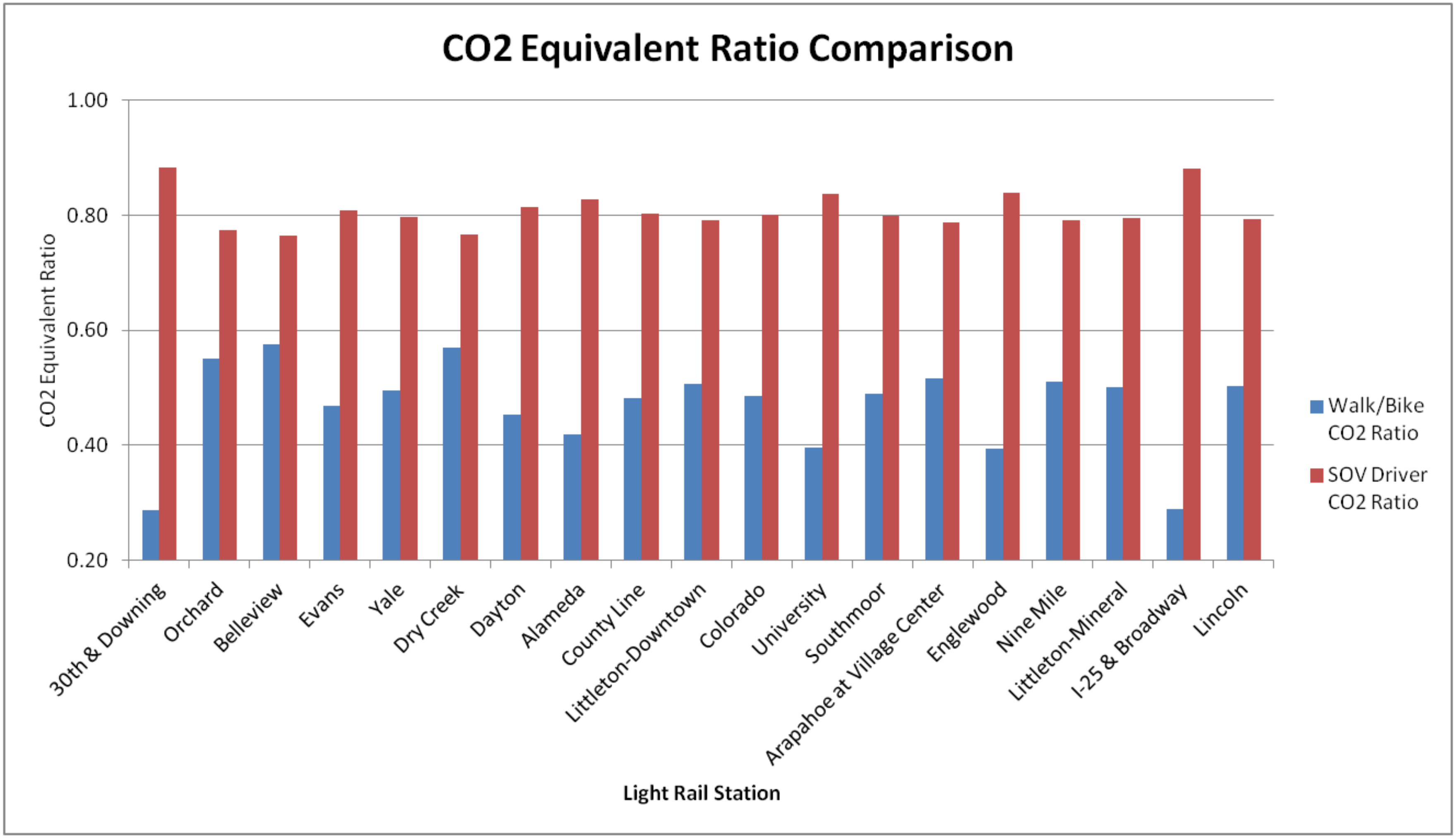

Figure 6: Walk/bike vs. SOV drive CO2-equivalent ratio

As seen in Figure 6, when the SOV transit access trip is substituted for walking or biking, the positive environmental effects of transit increase. Stations near downtown, such as 30th & Downing and I-25 &Broadway, exhibit the most change. Because walking and biking produce zero GHG emissions, the trip is even more sustainable than before. End of line stations tend to have a more drivers commuting a farther distance, while inner-corridor stations have a higher percentage of drivers commuting under two miles. This implies that inner-corridor stations may not be highly effective in facilitating sustainable transport, and instead, encouraging short vehicular trips that could otherwise have been made by walking or biking. Applying this concept to a broader scope, what would happen if light rail stations provided adequate biking and walking facilities within the station area? Perhaps drivers who otherwise would have driven to the PnR would now be able to walk or bike.

It is important that light rail facilities provide access to multiple modes. While PnRs are popular with drivers and allow for convenient access by automobile, the parking facility may also induce additional traffic. By providing adequate, safe facilities for pedestrians and cyclists, light rail stations become more accessible by alternative modes. In effect, these active modes of transportation may actually reduce PnR congestion and minimize the need for commuters to drive short distances to parking.

CHAPTER VI

CONCLUSION

PnR facilities are intended to increase transit ridership by providing convenient, free parking access to suburban commuters. However, PnRs may also produce unintended consequences. As shown by the results of this study, drivers can still make long trips to reach the PnR, commuting up to 30 miles to reach a lot. The vehicular emissions from these long, SOV transit access trips may negate the environmental benefits from using public transit. Illustrated by the CO_2-equivalent ratio, multi-modal trips that include a long SOV drive portion actually emit almost as many GHG emissions as a SOV drive-only trip. Thus, when a commuter makes a long drive to reach the PnR facility, the positive environmental effects of using light rail are nominal. On the other end of the driving spectrum, PnR facilities may also induce additional driving trips. As observed in the secondary analysis, up to 46% of PnR users drove less than two miles to reach the parking facility. Shorter drives of less than two miles could be substituted with walking and biking. Using an active mode of transport produces zero-emissions, and allows for the overall trip to become even more sustainable more the environment. However, when parking is over-abundant, users become less inclined to walk and bike to the stations, and instead, make a short driving trip, which is counterproductive in to the overall goal of a sustainable environment.

On a regional level, when drivers shift modes to incorporate transit into their commute, the community should benefit from a net reduction in greenhouse gas emissions. According to the DRCOG Congestion Database, the Denver region VMT for 2008 is 73.4 million VMT per day. Transferring this figure into CO_2 emissions, the

Denver region would benefit from a 2% reduction in CO_2 emissions from PnR users. While this figure appears to be a minor reduction, it actually grows larger when considering all transit users, including those who do not use PnRs. From the analysis CO_2 equivalent ratios, the results of this study found that end of line stations were amongst the more sustainable locations for PnRs. The geographic locations of these PnRs allow commuters to ride a longer distance on the light rail than if they were to drive closer into downtown. Nine Mile, Lincoln, and Littleton-Mineral stations are all end of line points for their respective corridors, and each station had a CO_2 equivalent ratio of 0.79. In comparison, 30th & Downing and I-25 & Broadway had a CO_2 equivalent ratio of 0.88. The higher ratio indicates that stations near downtown are less effective in facilitating sustainable habits. Providing free, convenient parking near downtown can be counteractive, such that drivers are provided an incentive to make a longer drive by car and shorter trip by transit. In order to promote the most sustainable transportation system possible, transit agencies should heavily consider the implications of parking supply and parking demand in station design. Furthermore, the cost of parking should be factored into the management of PnRs; providing free parking encourages drivers to disregard added miles and emissions to the trip. PnRs need to foster sustainable transportation, and currently, some lots may be underpriced for the market.

Moving forward, additional study can be done to evaluate how PnRs affect other modes of transit, including bus transit. The GHG emissions and environmental impact of buses are different than LRT, which may provide interesting insight for fleet management and vehicle technologies. Buses typically have a higher CO_2-equivalent per passenger mile because of diesel-based fuels.

There is still much more work to be done in advancing sustainable transportation and off-setting GHG emissions by transport. Looking forward, the role of PnRs in transit corridors should be one that complements sustainable transportation patterns. Instead of placing a PnR facility at each station, planners and stakeholders should consider a strategy that focuses on how PnRs can be most effective. Inner-corridor stations, particularly those closest to the downtown area, should be weary of creating induced traffic with parking facilities. End of line stations may be more effective in funneling suburban riders and maximizing their distance on transit. When used effectively, these facilities can provide a valuable tool to increase ridership and reduce GHG emissions. PnR facilities have played an important role in attracting choice riders from suburban areas, and allowing them a means to incorporate transit within their commute patterns. As more people become comfortable in using alternative transportation, the transport patterns of society will begin to shift, leading to a more sustainable tomorrow.

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